

METHODS, AMOUNTS, AND TIMING OF SPRINKLER IRRIGATION FOR WINTER WHEAT

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Written for Presentation at the
1994 ASAE International Winter Meeting
Sponsored by
ASAE

Atlanta Hilton and Towers
Atlanta, Georgia
13-16 December 1994

Summary:

The yield response of winter wheat to LEPA and spray irrigation methods was evaluated with four irrigation amounts ranging from non-irrigated to fully-irrigated in 33% irrigation increments. Grain yields for the LEPA and spray irrigation methods were essentially equal. For each 33% increase in irrigation amount, wheat yields increased a statistically significant 1.0 Mg/ha.

Keywords:

Irrigation, Irrigation Amounts, Irrigation Timing, LEPA Irrigation, Spray Irrigation

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METHODS, AMOUNTS AND TIMING OF SPRINKLER IRRIGATION FOR WINTER WHEAT¹

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ABSTRACT

The yield response of winter wheat to LEPA double-ended-sock, LEPA bubble and overhead spray sprinkler methods was measured in the Southern High Plains of the USA with four irrigation amount and two irrigation timing treatments. Irrigation amounts ranged from zero to 100% of soil water replenishment in 33% increments. Irrigation timing was evaluated with the 100% irrigation amounts but with spring irrigation delayed until booting or cut off during early grain filling. The wheat variety was TAM-202, the soil was Pullman clay loam and irrigations were applied with a lateral move irrigation system. For each 33% increase in irrigation, grain yields increased a statistically significant 1 Mg/ha. Yields were increased slightly by the LEPA methods in comparison to the spray method, but the difference was not statistically significant. Water use efficiency was significantly less for the non-irrigated treatment than for the irrigation amount treatments, but did not vary significantly among the irrigation methods. Irrigation water used efficiency was not significantly different for the application methods, irrigation amounts or irrigation timing. Based on the one year study that is being continued, any yield increase from LEPA irrigation of winter wheat in comparison with spray irrigation is small.

INTRODUCTION

Winter wheat, a major irrigated crop in the Southern High Plains, was initially surface irrigated but is now extensively irrigated with center pivot irrigation systems. The pioneering study by Jensen and Sletten (1965) estimated evapotranspiration (ET) for winter wheat and provided guidelines for maintaining soil water and fertility levels. Recent ET measurements with weighing lysimeters by Howell et al. (1993) show larger ET values than had previously been determined with water balance estimates. Irrigation management guidelines for winter wheat have been summarized by Musick and Porter (1990).

For sprinkler irrigation in the Southern High Plains there has been a nearly complete transition from impact sprinklers to spray heads. For summer crops there has been an additional transition from spray systems to Low Energy Precision Application (LEPA) systems (Fipps and New, 1990). LEPA irrigation offers substantial increases in application efficiency over spray irrigation (Lyle and Bordovsky, 1981, 1983; Schneider and Howell, 1990), but at the expense of requiring higher levels of management. During recent years, LEPA irrigation has been used by some growers on winter wheat even though it is often flat-planted in closely spaced rows and has no surface reservoir storage for the high-rate applications. If the water can be managed without appreciable runoff or redistribution, LEPA offers potential for eliminating air evaporation and reducing crop canopy and soil evaporation losses (Schneider and Howell, 1993).

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Winter wheat can be efficiently deficit-irrigated (Dusek and Musick, 1992), and LEPA irrigation is an efficient method of deficit irrigation (Schneider and Howell, 1993). Wheat has the potential to use small amounts of irrigation throughout the growing season (English and Nakamura, 1989), but it also has the potential to efficiently utilize large irrigations at critical growth stages (Dusek and Musick, 1992; Schneider et al., 1969). The combination of LEPA and deficit irrigation thus offers potential for efficient use of irrigation water by winter wheat.

This study compares LEPA and spray irrigation using full irrigation and deficit irrigation based on percentages of full irrigation. Timing of irrigations to avoid water stress at known critical crop development stages was also evaluated.

PROCEDURE

The research was conducted at the USDA Conservation and Production Research Laboratory at Bushland, TX during the 1993-94 wheat cropping season. The soil at the experimental site is Pullman clay loam a fine, mixed, thermic torrefic Paleustolls. The research field has a uniform slope of 0.0025 m/m in the direction of travel of the lateral move irrigation system and a 0.0022 m/m cross slope.

Experimental Design:

One spray and two LEPA sprinkler application methods were evaluated with four irrigation amount treatments and two irrigation timing treatments. Field plots were arranged in a randomized block design with irrigation treatments being the blocks and sprinkler methods being randomized within each replicate of a block. The treatments were replicated three times. Plots were 12 m wide by 20 m long, and the irrigation treatment blocks were separated by 5-m wide borders.

LEPA irrigation methods were double-ended Fangmeier LEPA drag socks (Fangmeier et al., 1990), designated as M_1 , and LEPA bubble emitters (Fipps and New, 1990), designated as M_2 . The Fangmeier socks were drag along the ground, and the LEPA bubble emitters were placed about 0.3-m above ground. The spray irrigation method was above canopy spray, designated as M_3 , with the level of application about 1.5 m above ground.

A fully-irrigated control treatment and five deficit irrigation treatments were evaluated with the three sprinkler methods. Irrigations were scheduled according to the average soil water in the three plots being fully-irrigated with LEPA double-ended socks (I_{100}/M_1). Irrigations were applied to maintain soil water in the 1.0-m deep profile of the I_{100}/M_1 control treatment above 70% of field capacity which is approximately 296 mm of total soil water for the Pullman clay loam soil. Other irrigation amount treatments designated as I_0 , I_{33} and I_{67} received 0, 33 or 67% of applications to the fully-irrigated treatments on the same day. Irrigation size was changed by changing the speed of the lateral move irrigation system. The irrigation timing treatments received the same-sized irrigations as I_{100} but spring irrigation was delayed until early boot on I_0 and cut off during early grain filling on I_6 .

Gravimetric and neutron soil water measurements were combined to provide data for both soil water depletion and irrigation scheduling. All plots were gravimetrically

sampled by 0.3-m increments to a 1.8-m depth at planting, at the beginning of spring growth and after harvest. Soil water in the I_{100} irrigation plots was also measured in 0.2-m depth increments to a 2.4-m depth with a locally field calibrated CPN Model 503DR³ neutron moisture meter. From the start of spring growth until crop maturity, weekly measurements were made for scheduling irrigations except when rainfall made irrigation unnecessary.

Irrigation Equipment:

Irrigations were applied with a hose fed Valmont³ Model 6000 lateral move irrigation system equipped with a CAMS computerized controller. The system had three, 39-m long spans providing space for twenty four 1.52-m spaced drops under each span. Pressurized water, on demand from a surface reservoir, was supplied to the irrigation system through an underground pipeline and a 114 mm diameter surface hose. Information about the three types of application devices is listed in Table 1. Senninger³ 360° spray nozzles placed above the LEPA socks metered the flow to the socks at the same rate as the other devices. All application devices were spaced 1.52 m apart and discharged 19.0 L/min. Pressure to the application devices was 207 kPa, but the LEPA applicators were equipped with 41-kPa pressure regulators.

Cultural Practices:

Cultural practices were similar to those generally used for irrigated wheat production under center pivot irrigation systems in the Southern High Plains. Table 2 lists fertilizer rates, plant population and dates of important cultural and irrigation operations. The field area had been cropped to dryland grain sorghum during the summer of 1992 and fallowed with sweep tillage until anhydrous ammonia fertilizer was applied Sept. 21, 1993. The wheat was planted on Oct. 6 with a 6.1-m wide Tye³ drill having 0.25-m spaced double-disk openers. The wheat rows were oriented perpendicular to the direction of travel of the sprinkler system. A 25-mm emergence irrigation was required on October 12. Because of unexplained blockage in some of the grain drill drop tubes, three one-drill-width strips had to be replanted on Oct. 25. Irrigation blocks were separated by dikes to prevent runoff from wetter treatments onto drier ones, and sprinkler method plots were separated by small ditches to prevent runoff from LEPA plots onto spray plots.

Grain yield samples were harvested with a Hagy³ plot combine having a 1.52-m wide header on June 29, 1994. One square meter plant samples were also collected from June 24-29 to obtain total dry matter, grain weight, individual seed weight and an independent measure of grain yields. The plant samples were oven dried at 70 °C. Then, the grain was threshed, grain weight was determined and seed weight was measured with a 500-grain subsample. Grain yields were adjusted to 13% water content on a wet weight basis.

³The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation or exclusion by the USDA-Agricultural Research Service.

RESULTS

Irrigation and Rainfall:

The amount and timing of spring irrigations and rainfall are listed in Table 3. The I_{100} treatments generally received one 25-mm irrigation per week from early March to early May and then received two 25-mm irrigations per week until early June. Two exceptions were the week of April 24-30 with 17 mm of rainfall and the week of May 15-21 with 35 mm of rainfall. Total spring irrigations were 350, 234 and 117 mm for the three irrigation amount treatments and 250 mm for the two irrigation timing treatments. Rainfall during the spring irrigation interval totaled 100 mm.

Soil Water:

The field area had been fallowed for 11 months prior to planting, and the average plant available soil water in the 1.8-m profile was about 210 mm. There was some non-uniformity of the soil water, however. The I_0 irrigation plots at the east edge of the field received some runoff water from an adjacent waterway, and the soil water in the 1.8-m profile was about 40 mm larger than for the remainder of the field area. Also, with the non-irrigated plots excluded, the M_2 treatment plots had about 30 mm less water in the 1.8-m profile than the M_1 and M_3 treatment plots.

Soil water for the 1.0 and 2.4-m profiles in the control irrigation treatment (I_{100}/M_1) is illustrated in Figure 1. The target soil water content for the top 1 m of soil was 296 mm, and the measured soil water levels were generally at or above this level. The one exception was on May 5 when the 1.0-m soil water level dropped 26 mm below the target level.

Profile soil water depletion amounts are given in Table 4 for the different treatments. Wheat is known to extract and fully utilize soil water from deep depths in the Pullman soil. The full irrigation treatment (I_{100}) had a mean depletion of 57 mm, the deficit irrigated treatments (I_{67} , I_{33}) had depletions of 100 and 87 mm respectively and the non-irrigated treatment had depletion of 152 mm. The differing depletions with the deficit irrigations may have been due in part to different rooting patterns and biomass partitioning due to water deficits. The early cutoff treatment (I_0) permitted 69 mm greater depletion than I_{100} which partially offset the 100 mm greater irrigation. However, the delayed irrigation treatment (I_0) only increased depletion 28 mm over I_{100} . Deficit irrigation levels, particularly with moderate deficits, and early seasonal irrigation cutoff permitted greater use of the available soil water which can partially reduce seasonal irrigation requirements.

Grain Yields:

Grain yields for each of the sixteen sprinkler method-irrigation amount combinations are listed in Table 4. In addition, grain yields averaged by sprinkler methods and irrigation treatments are listed in Table 5. Yields for the two LEPA methods were slightly larger than for the overhead spray method, but the difference was not significantly different ($p \leq 0.05$). Grain yields increased about 1 Mg/ha for each irrigation amount increment, and all irrigation-amount treatments were significantly different ($p \leq 0.01$). For a valid analysis, all of the statistical differences presented here are for the irrigation amount treatments only.

Grain yields for the two irrigation timing treatments are also listed in Table 5. The early cutoff full irrigation treatment yielded 0.25 Mg/ha more than the comparable I_{67} treatment while the delayed full irrigation treatment yielded 0.52 Mg/ha less.

Harvest index and individual grain weight are listed in Table 4. Harvest index increased slightly with irrigation amount, but the differences were not significantly different for either the sprinkler methods or the irrigation amounts. Seed weight was not significantly different for the sprinkler methods, but it was significantly less ($p \leq 0.05$, $LSD = 1.7$ mg) for the non-irrigated treatment than for the two larger irrigation amount treatments.

Water Use Efficiency and Evapotranspiration:

Water use efficiencies (WUE) calculated as grain yield divided by evapotranspiration are listed in Table 4 for the sprinkler method-irrigation amount combinations. Water use efficiency was significantly less for the non-irrigated treatment ($p \leq 0.01$, $LSD = 0.115$ kg/m³) than for the three irrigation amount treatments, but the three irrigation amount treatments were not significantly different from each other.

Irrigation water use efficiencies (IWUE) calculated as the irrigated yield minus the non-irrigated yield divided by the irrigation amount are also listed in Table 5. Irrigation water use efficiencies were not significantly different for either the sprinkler methods or the irrigation amounts ($p \leq 0.05$).

Evapotranspiration for all treatment combinations is listed in Table 4 and ranged from 334 mm for the non-irrigated treatment to 589 for the I_{100} treatment. The ET values for the fully-irrigated treatments are considerably less than ET measured with weighing lysimeters during three years at Bushland (Howell et al., 1994). This suggests there was some stress during the early-May interval. Grain yields as a function of ET are illustrated in Figure 2. The yields are linearly related to ET with $r^2 = 0.861$. The regression slope of 0.93 kg/m³ may be a better characterization of wheat yield response to water than either WUE or IWUE.

DISCUSSION

The grain yields in this study are low in comparison to yields of 6.0 Mg/ha or more for irrigated research plots in the Southern High Plains. The yields are substantially better though than the 2.68 Mg/ha average irrigated yield reported for the area by Musick and Porter (1990). The low yields may have resulted from the severe spring weather and water stress during the late spring. Two hard freezes occurred during late April when the wheat was starting into the grain filling stage. Freezing weather at this stage of winter wheat growth has been shown to cause major yield reductions. In addition to the freezing weather, there were several days in March and May with hot dry winds that stressed the wheat crop. The reduced soil water levels in early-May are believed to have caused the reduced ET and correspondingly reduced grain yields. In future years of the study more careful monitoring of soil water will prevent this.

The nonuniform soil water across the experimental area at planting time likely contributed to the data variability and large LSD's in the statistical analysis. We have no explanation for the 30 mm lower level of soil water among the M_2 sprinkler method plots.

The extra 40 mm of soil water in the non-irrigated, I_0 , plots would be expected to increase the grain yields for that treatment and reduce irrigation water efficiencies for other treatments. If this variability occurs during future years of this study, all plots will be uniformly irrigated during the fall or early spring in order to start the spring irrigations with more uniform soil water among the plots.

There has been some concern about crop damage from dragging double-ended LEPA socks through wheat. With our June 9 irrigation cutoff date, the wheat was still green enough to recover from the LEPA double-ended socks dragging through the crop. There is also concern about runoff or redistribution of LEPA applied water on flat planted winter wheat. We did observe some runoff from the I_{100} irrigation treatments, but the dense wheat foliage minimized runoff, and we would not consider it a problem on commercial wheat fields.

CONCLUSIONS

1. Grain yields were significantly increased by irrigation amount with a 1 Mg/ha yield increase for each 33% increase in irrigation.
2. Grain yields did not vary significantly between LEPA and spray sprinkler irrigation methods.
3. For 100% irrigation of winter wheat with an early cutoff, irrigation amount, grain yields and water use efficiencies were essentially the same as for the 67% deficit-irrigated wheat. Delaying spring irrigation followed by 100% irrigation amounts reduced grain yield to 3.11 Mg/ha in comparison to 3.63 Mg/ha for the 67% irrigation amount and decreased water use efficiencies.
4. The highest WUE occurred with 100% irrigation, but the highest IWUE occurred with deficit irrigation.

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Table 1. Irrigation application device information.

Device	Manufacturer ³	Model	Nozzle Diameter mm
LEPA Sock	A.E. Quest & Sons (Senninger)	(360°) ⁴	(6.8)
LEPA Bubble	Senninger	Quad IV ⁴	6.8
Overhead Spray	Nelson	Spray I	4.6

⁴ Equipped with 41 kPa pressure regulators.

Table 2. Agronomic data for the 1993-94 winter wheat crop.

Variable	1993-94
Fertilizer Applied	100 kg(N)/ha 112 kg(P)/ha
Wheat Variety	TAM-202
Planting Date	Oct. 6, 1993
Emergence Irrigation Date	Oct. 12, 1993
First Seasonal Irrigation Date	March 23, 1994
Last Seasonal Irrigation Date	June 9, 1994
Harvesting Date	June 29, 1994
Plant Population, plants/m ²	265

Table 3. Weekly rainfall and irrigation to the fully-irrigated treatments.

Week	Irrigation I ₁₀₀ Treatments	Rainfall -----mm-----	Weekly Totals
March 20-26	25	0	25
March 27-April 2	25	0	25
April 3-9	25	0	25
April 10-16	25	9	34
April 17-23	25	9	34
April 24-30	0	17	17
May 1-7	25	7	32
May 8-14	50	6	56
May 15-21	50	0	50
May 22-28	0	35	35
May 29-June 4	50	9	59
June 5-11	50	8	58
Totals	350	100	450

Table 4. Grain yields, evapotranspiration, soil water depletion, water use efficiency, harvest index and seed weight.

Irrigation Amount	Sprinkler Method	Yield Mg/ha	Soil Water Depl. mm	ET ⁶ mm	WUE kg/m ³	IWUE kg/m ³	Harvest Index	Seed Weight mg
100%	LEPA Sock	4.39	85	617	.712	.778	.336	25.7
	LEPA Bubble	4.73	39	571	.829	.876	.359	26.3
	Overhead Spray	4.37	46	578	.757	.772	.386	26.7
	Average	4.50	57	589	.766	.809	.360	26.2
67%	LEPA Sock	3.82	97	513	.745	.917	.345	27.0
	LEPA Bubble	3.35	85	501	.669	.719	.339	25.3
	Overhead Spray	3.71	117	533	.696	.871	.334	26.9
	Average	3.63	100	516	.703	.836	.339	26.4
33%	LEPA Sock	2.90	97	396	.733	1.06	.313	25.7
	LEPA Bubble	2.44	70	369	.660	.661	.334	25.4
	Overhead Spray	2.46	92	391	.629	.679	.355	25.6
	Average	2.60	87	385	.674	.800	.334	25.6
0%		1.67	152	334	.500		.328	24.3
100% Delayed	LEPA Sock	2.97	82	514	.579	.521	.343	22.1
	LEPA Bubble	3.22	77	509	.632	.620	.328	23.0
	Overhead Spray	3.13	96	528	.593	.584	.394	22.9
	Average	3.11	85	517	.601	.575	.355	22.7
100% Early Cutoff	LEPA Sock	3.81	129	561	.679	.856	.320	23.3
	LEPA Bubble	4.10	97	528	.777	.972	.323	22.7
	Overhead Spray	3.72	153	585	.636	.821	.315	22.9
	Average	3.88	126	558	.697	.883	.319	23.0

⁶Includes 182 mm growing season precipitation.

Table 5. Grain yields for three sprinkler methods averaged across four irrigation amounts, for four irrigation amounts averaged across three sprinkler methods and for two irrigation timing treatments.

Sprinkler Method	Yield Mg/ha	Irrigation Amount	Yield Mg/ha
LEPA Sock	3.20a ⁴	100%	4.50a
LEPA Bubble	3.07a	67%	3.63b
Overhead Spray	3.02a	33%	2.60c
		0%	1.67d
LSD (0.05)	0.38		0.38
		100% Delayed ⁵	3.11
		100% Early ⁵ Cutoff	3.88

⁴Yields followed by the same letter are not significantly different ($p \leq 0.05$).

⁵Not included in analysis of variance.

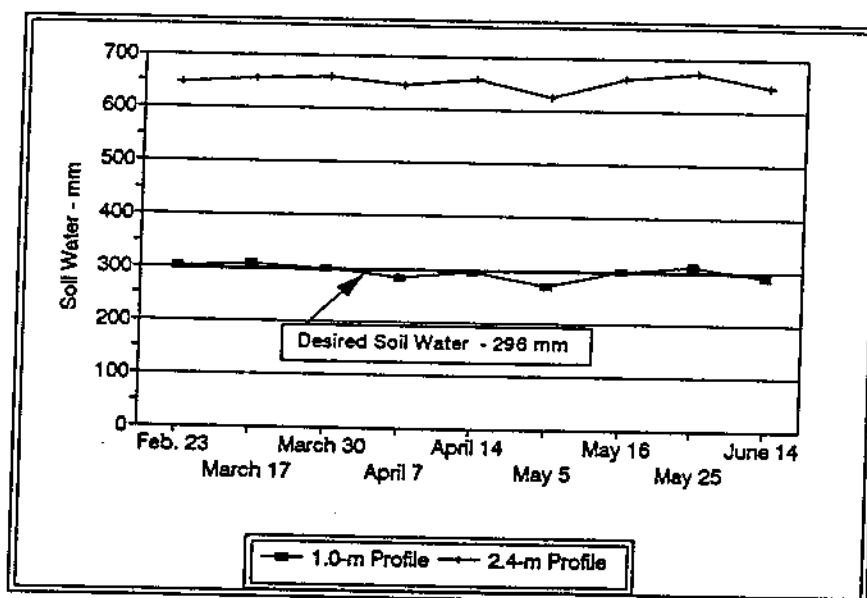


Figure 1. Total soil water in the 1.0 and 2.4-m soil profiles during the 1994 spring irrigation season for the control treatment.

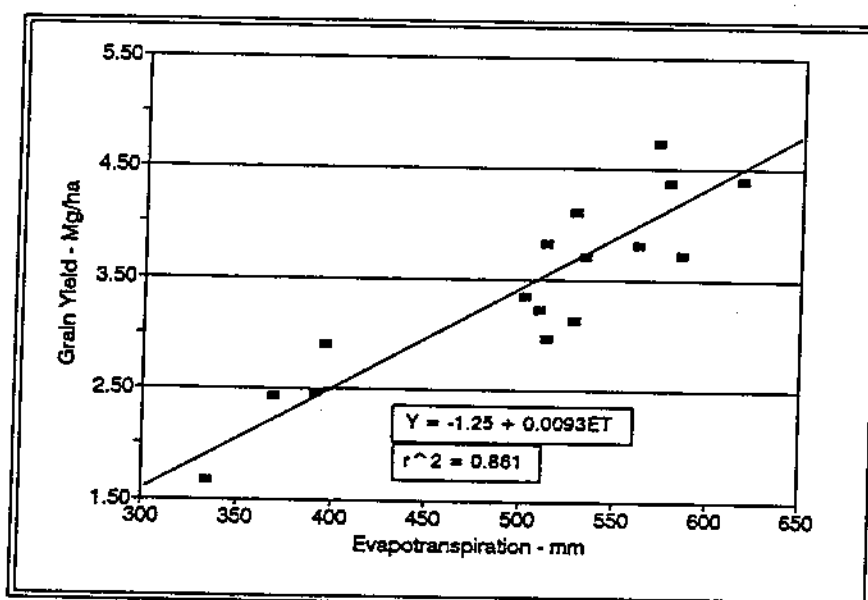


Figure 2. Grain yield as a function of evapotranspiration for the sixteen sprinkler method-irrigation treatment combinations.